REDUCING RIB DEFLECTION IN THE IIHS TEST BY PRELOADING THE PELVIS INDEPENDENT OF INTRUSION

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ABSTRACT

A cooperative research project with the National Highway Traffic Safety Administration (NHTSA) was conducted to evaluate the capability of a Tubular Thoracic Cushion (TTC) airbag concept to significantly reduce rib deflections for the SID-IIs dummy in the Insurance Institute for Highway Safety's (IIHS) side-impact barrier test.

The concept of the TTC airbag was to efficiently distribute a majority of the crash force to the pelvis, which is more able to tolerate forces from side-impact crashes. The characteristic of the airbag to develop tension when deployed appeared to offer additional opportunities for occupant restraint in the IIHS side-impact environment.

Computer analysis confirmed that an approach of interposing an inflatable cushion between vehicle occupants at the ribs and a vehicle's intruding side structure may be problematic when attempting to limit rib deflection, particularly for small-stature occupants.

NHTSA analysis of NCAP side-impact tests suggested that pelvic lead (pelvic loading prior to the loading of the rib cage) lessens severity of thoracic injury [1]. Simulations of the IIHS side-impact barrier test utilizing this approach of pelvic lead with the TTC device showed reductions in rib deflection to a 5th percentile female dummy when airbag inflation was limited only to the pelvis region.

Due to the characteristic of the TTC airbag to develop tension when deployed, a strategy of applying an inboard lateral "pre" load to the pelvis region of the SID-IIs dummy prior to intrusion was developed. This further reduced rib deflection in dynamic simulations and was validated in dynamic sled testing. The tensioning characteristic of the TTC airbag concept demonstrated pre-loading the pelvis of an occupant in the IIHS side-impact environment provided significant reduction in injury risk.

BACKGROUND

Side-impact crashes represent the most hazardous crash mode of all planar crashes. Based on 1999 US NASS data, the frequency of these crashes comprises approximately one fifth of all planar crashes. However, 1999 US FARS data indicates more than a third of all occupants fatally injured are disproportionately represented in side-impact collisions.

There are several reasons why side-impact collisions have the highest injury potential over frontal impact crashes. Unlike frontal crashes, side crashes involve considerably less crush space between the point of impact from the striking vehicle and the struck passenger [2]. Consequently, this very limited crush space increases the protection requirements on the vehicle side-structure, interior padding, and other countermeasures such as side airbags.

During a side-impact crash, the door of the struck vehicle intrudes into the passenger compartment with the velocity of the striking vehicle. The occupant in the struck vehicle remains motionless relative to the intrusion until the distance between the occupant and the intruding door come together and the door accelerates the occupant. The struck vehicle is accelerated as a result of the stiffness of the side structure. The intrusion of the door is complete when the velocity of the door is equal to the velocity of the vehicle. Later in the crash event, the velocity of the occupant becomes greater than the intrusion velocity and the occupant separates from the intrusion. However, the highest risk of injury is likely to occur much earlier in the crash event [3].

Changes to U.S. Vehicle Fleet

A significant shift in the United States' vehicle fleet composition appears to be greatly increasing the hazards associated with side-impact crashes [3]. This shift is due to increased popularity of sport utility vehicles, vans and light trucks.

Side-impact crashes of light vehicles, i.e. passenger cars and multi-purpose vehicles (MPV's) result in approximately 9,800 fatalities and over 1,020,000 injuries each year (1996 FARS and GES). This corresponds to about 30% of vehicles involved in tow away crashes. Also, over 43% of the fatalities and 37% of the serious injuries (MAIS 3) in U.S. light vehicle side-impact crashes are in side impacts where an MPV is the striking vehicle (based on a yearly average from the current U.S. crash environment (1988-1996 NASS/CDS and FARS).

Based on analysis of Canadian field accident data and crash testing, 67% of passenger car occupants injured at the AIS 3 or greater level, sustained their injuries in impacts where the striking vehicle was an MPV [4]. Additionally, it was observed that female occupants were over-represented among seriously injured occupants.

These recent real-world changes in the vehicle fleet have shown to present technical challenges in protecting occupants in this more difficult circumstance. The hood heights of MPV's such as sport utility vehicles typically correspond with the head of an occupant seated in a passenger car. This situation exposes the occupants in a passenger car to the risk of serious head injuries in a side-impact. However, risk of torso injury to the occupant in the passenger car also increases as a result of the proximity of the hood height of the MPV.

The side-impact test program developed by the Insurance Institute for Highway Safety (IIHS), addresses this real-world scenario. The basis for this side-impact test program is illustrated in figure 1.

Courtesy of IIHS

Figure 1. IIHS test demonstration for consumer information side crash test

The design of the IIHS side-impact test is to assess the protection afforded to both the head and torso of small-stature occupants in passenger cars struck in the side by MPV's. Results from tests conducted on a variety of vehicles equipped with and without side airbags has shown the test to be a significant challenge for vehicle manufacturers to demonstrate satisfactory performance especially for torso protection.

INTRODUCTION

There are several approaches to side-impact protection for passenger vehicles. These generally include vehicle intrusion stiffness, interior geometry, and inflatable devices and padded structures capable of absorbing the impact energy.

Minimal improvements in reducing intrusion velocity are possible through stiffening the vehicle structure, however; sufficient thoracic protection is not likely without additional countermeasures to meet the requirements in the IIHS side-impact scenario.

Investigation into potential safety benefits of padding using constant crush force energy absorbing materials for thoracic protection in side impacts have been studied over several decades [5]. Some analysis indicates 15-30% potential reduction of thoracic injury risk for selected material characteristics as an upper bound [6]. Another study has shown approximately 10% effectiveness for padding in the door and armrest as an injury countermeasure in side crashes [5]. However, reducing the risk of injury to the chest and abdomen in the IIHS situation with padding countermeasures appears more difficult.

Side Airbag Functions

Most types of side airbags are designed to establish early contact between the door and occupant. This interaction with the airbag accelerates the occupant before the intruding door contacts the occupant. These airbags are designed to distribute the contact forces over a large area of the rib cage to avoid localized loads and reduce the overall risk of thoracic injuries. A critical challenge of an airbag design is to inflate the airbag with sufficient pressure to accelerate the occupant from the intrusion while appropriately cushioning the occupant to minimize the risk of rib fractures.

Loading the pelvis prior to contact with the thorax is a favorable occupant kinematic and is often referred to as "pelvic lead." This occupant motion is indicative of reduced injury risk to the thorax [1] [3].

As such, a strategy of distributing greater contact load to the pelvis region appears appropriate due to higher loading tolerance of the pelvis (Injury Assessment Reference Value 4kN per IIHS evaluation) compared to rib structures. Therefore, padding in the door itself is often used to push the pelvis region to accelerate the occupant with the lowest possible risk. Some side airbags cover not only the thorax but also the pelvis region to minimize potentially injurious loads to the thorax and abdomen.

The interior door trim contour is another important design consideration in addressing the risk of injury in side-impact. The Institute's experience in the development of their side-impact program has identified the abdomen as a critical area of concern [3]. This is an interesting finding, considering that injuries to the spleen are common in serious side impacts. The deformed door can protrude more significantly at the armrest, which can increase the risk of abdominal injury. Some airbag designs fill these irregular contours to provide a large flat contact zone between the intrusion and occupant to avoid localized loads and minimize the risk of abdominal injuries.

Airbag Deployment Timing

One of the single most important deployment characteristics necessary for inflatable devices to mitigate injury in side-impact crashes has to do with the timing of the airbag. Side collisions require a much faster airbag reaction time compared to frontal collisions [7]. This is due to the limited distance and time to sense the crash and insert the airbag between the occupant and intruding structure. Therefore, deployment time of an airbag is critical, especially in more severe side-impact crashes.

Analysis of thoracic dummy responses from test results in some IIHS side impact tests show more than 42 mm of rib deflection for a SID-IIs dummy after 25 milliseconds after initiation of barrier impact. This magnitude of rib deflection represents a 50% risk of AIS3+ injury. NHTSA identifies 42mm of rib deflection represents

PROJECT DESCRIPTION

A cooperative research project with NHTSA was established to evaluate the capability of a Tubular Thoracic Cushion (TTC) concept airbag with a contracting characteristic that offered possibilities to significantly reduce rib deflections of the SID-IIs dummy in IIHS side-impact environment. The project was divided into two major tasks. The first task consisted of computational analyses intended for design development of the concept airbag. The second major task for the research project included dynamic tests of prototypes airbags for model validation and evaluation of concept feasibility.

Model Development

The primary occupant-simulation software used to evaluate various design iterations of the concept airbag was MADYMO (Mathematic Dynamic Modeler). A full-scale crash test identified in the IIHS database (1999 Pontiac Grand Am, test #CS01009) was used for developing the baseline computer model. The model was used to simulate the IIHS Grand Am test and then apply the airbag design iterations based on occupant dynamic responses. The Grand Am vehicle configuration was equipped without deployable side-impact countermeasures. The vehicle test was selected without side airbags to eliminate the complications of other inflatable countermeasures and so design iteration could be based on occupant response interaction with the vehicle's intrusion profile.

This multi-step process consisted of creating a baseline model correlated to the occupant responses measured in the IIHS test. Various airbag designs were created and implemented into the baseline model, and iterated on the designs until occupant response goals were achieved.

A modeling technique called Prescribed Structural Motion (PSM) was used to recreate door intrusion. This technique assigns motion to the nodes of an FEM structure according to 3-D displacements in time. Since the IIHS test procedure includes digitized FARO data of the outer door panel pre and post-test, the door intrusion was recreated by assigning displacement of FEM nodes from the pre-test coordinates to the post-test coordinates. Figure 2 illustrate the outer door mesh at the pre and post-test conditions in the model.

Figure 2. PSM of outer door structure in MADYMO

Outer door motion was prescribed for all nodes in the representative mesh. Only the nodes along the perimeter of the inner door mesh were prescribed to transfer this motion to the inner door. This allowed the inner door panel to deform independently from the outer door based on material properties assigned to the inner door surface. The baseline MADYMO model was completed by defining contact between the occupant and door, assigning generic material properties to the inner door surface, and prescribing motion with a rough approximation of intrusion rate. The baseline model was simulated and the occupant responses in the model were compared to the IIHS test results.

Occupant responses used to correlate the MADYMO model and IIHS results included: rib deflection and velocity, pelvic force and acceleration, and shoulder force and deflection. Initial model results showed the magnitude and timing of these responses needed adjustment to match the IIHS test results. Model input parameters used to match occupant responses included, outer door intrusion rate, inner door material properties, seat attachment deformations, and friction coefficients

Problem Definition & Injury Metrics

Before performing model iterations on the airbag designs, it was necessary to establish injury metrics to measure the effectiveness of each design. An extensive review of the IIHS test data showed severe rib deflection and rib deflection rate above injury tolerance levels for the 5th female occupant. Crushing injuries in a chest impact tend to be characterized by extensive rib fractures before soft tissues are involved [8]. Consequently the primary injury metric used to evaluate effectiveness of the airbag design in preventing thoracic injury was rib deflections.

The 5th female occupant seated height exposes her to increased risk of abdominal rib deflection due to the location of the armrest in the Grand Am vehicle. This situation is reflected in the data as the lower abdominal ribs show greater deflection (~56mm) than the thoracic ribs (~41mm) and correspond to the armrest location. All rib deflections exceeded the injury assessment reference value (IARV) of 34mm for the thoracic ribs and 32mm for the abdominal ribs. Therefore, an airbag solution would need to be designed to reduce loading to all the ribs and minimize the affects of the intrusion at the abdominal ribs.

Other occupant responses, such as pelvic force and shoulder displacement and force, and spinal acceleration were monitored to ensure injury risks were not induced in other body regions due to the TTC designs.

Occupant Response Comparison

The SID-IIs dummy utilizes five independent ribs to measure rib deflections during side impacts. The top three ribs represent the thoracic region while the bottom two represent the abdominal region.

The process of establishing a satisfactory baseline simulation consisted of correlating known input variables and comparing occupant response values between the IIHS test data and model simulation. In the IIHS test, individual rib deflection and velocity responses in the thoracic region were all similar in magnitude and timing. Abdominal rib deflections and velocities were also similar, but of a higher magnitude than the thoracic ribs due to the impact from the armrest. Table 1 shows the magnitude of rib deflection and the time of initial contact between the inner door and occupant for both the IIHS test and MADYMO model. The difference in impact severity between the thoracic and abdominal regions prompted separate comparisons of each body region between the model and the test.

Table 1.
Comparison of peak occupant responses and initial contact timing in IIHS test and MADYMO simulation

Peak Occupant Response	IIHS Test		MADYMO	
	Value	Time (sec)	Value	Time (sec)
Thoracic Rib Deflection (mm)	41	0.021	34	0.023
Abdominal Rib Deflection (mm)	56	0.018	52	0.022
Shoulder Force (N)	2310	0.019	2090	0.018
Pelvic Force (N)	3300	0.019	3340	0.025

The initial TTC design activities were conducted in a simulated dynamic environment and were important that an acceptable correlation between the baseline model and real-world IIHS data was achieved. It was then determined the baseline MADYMO correlation for timing and magnitude of the occupant responses in multiple body regions was satisfactory for the TTC design effort.

DESCRIPTION OF AIRBAG CONCEPT

The TTC is a seat-based airbag that utilizes a contracting feature of its design. The TTC design is contoured around the occupant's pelvis and lower back to an attachment point on the inboard seatback structure as shown in figure 3.
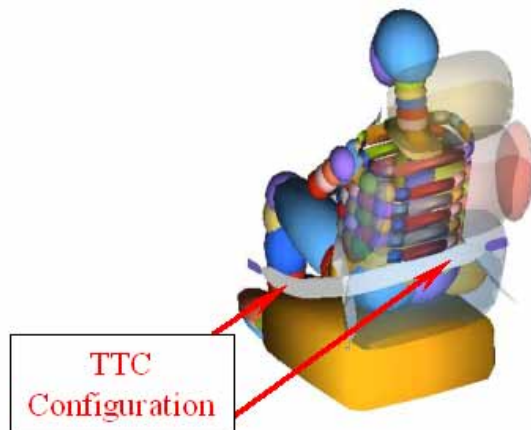

Figure 3. Model of TTC with seated occupant

Upon inflation, the tubular airbag increases in diameter while significantly shortening its length. This contracting characteristic can develop significant axial tension between its end attachments, which is used to provide significant occupant restraint in side-impact crashes.

AIRBAG DESIGN DEVELOPMENT

The capability of MADYMO to accurately simulate airbag deployment characteristics and represent the IIHS dynamic impact event proved ideal for optimizing the TTC design for improved restraint performance. Multiple design iterations were investigated including optimizing airbag coverage, attachment locations, vents, shapes and inflator characteristics.

A prototype TTC was fabricated and attached to a test fixture then deployed with an inflator. The pressure response from this test was used to define the properties of the inflator function and material properties of the simulated TTC. The model correlation of the deployment results is shown in figure 4.
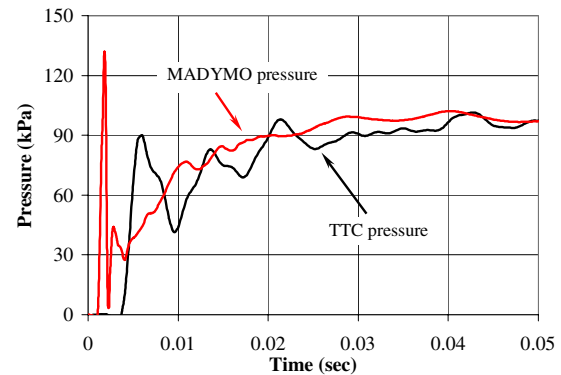
Figure 4. Model correlated to deployment test data

DESIGN SOLUTION

All previous TTC design iterations utilized approaches that interposed the inflatable cushion between vehicle occupants at the ribs and a vehicle's intruding side structure. This approach was unable to sufficiently minimize rib deflections within IARV's. Methods of augmenting additional pelvis interaction while limiting rib interaction demonstrated substantial performance benefits. Nevertheless, these approaches were not within the goals of the IARV requirements.

However, another approach was investigated to better utilize the tensioning characteristic of the contracting TTC feature. A design iteration was developed that consists of an TTC airbag applying a lateral "pre-load' to the pelvis region of the occupant. To accomplish this, the TTC is attached at the front of the seat bottom as previous designs while the rear attachment is routed across the seat back and attached to the inboard seatback structure.

When the TTC is inflated, the tubular airbag contracts between its attachments to create tension. As the TTC contracts to form a straight line between it's end attachments, an inboard force is applied against the occupant's pelvis to accelerate the occupant inboard and away from the intruding door. This strategy facilitated inboard movement of the occupant to minimize interaction with vehicle intrusion. A mockup of the TTC is shown in figure 5.

Figure 5. TTC mockup located with pelvis region

Thoracic and abdominal peak rib deflections were significantly decreased with the final TTC design iteration. Comparisons of the SID-IIs rib deflection responses in crash test simulations with and without the TTC are shown in figures 6 and 7.
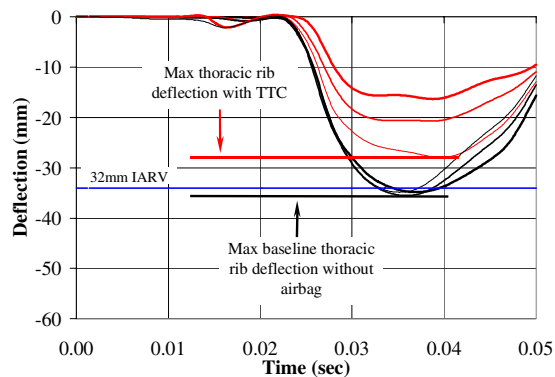

Figure 6. Comparison of thoracic rib deflection for IIHS simulations with and without TTC
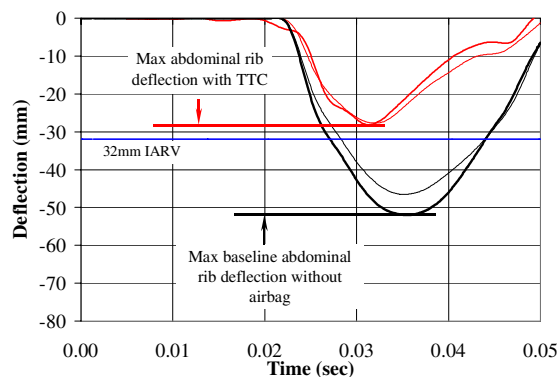
**Figure 7. Comparison of abdominal rib deflection for IIHS simulations with and without TTC**

PRELOADING THE PELVIS INDEPENDENT OF INTRUSION

The timing of the pelvic response for the baseline test condition was compared to a pelvis-only airbag to identify timing differences when the interaction from the intruding door structure contacts the dummy. The timing of load applied to the pelvis by the pelvis airbag occurs at approximately 14 milliseconds. This contact timing with the pelvis airbag is earlier than the baseline due to the thickness of the airbag. This comparison is shown in figure 8.
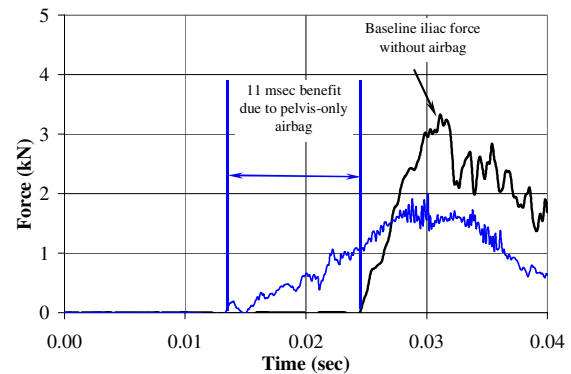
Figure 8. Difference in pelvis response timing for pelvis-only airbag and baseline condition

The pelvis force response time shown in figure 9 illustrates a dramatically earlier pelvis response with the TTC than the pelvis only airbag by approximately 9milliseconds. The inflated airbag thickness of the TTC was the same for the test with pelvis only airbag. Therefore, the earlier response was apparently a result of the contracting feature of the TTC that applied a inboard lateral "pre-load' to the pelvis region of the occupant.
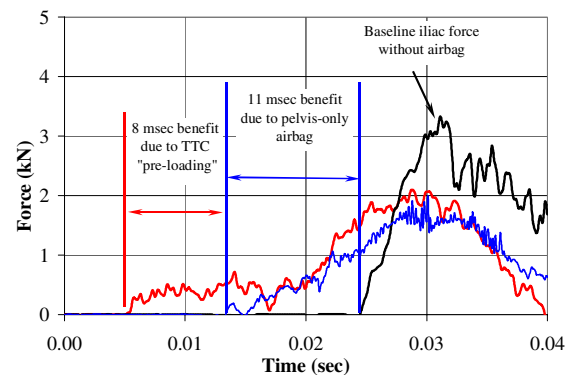

Figure 9. Timing of TTC pre-loading pelvis

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PROOF OF PRE-LOAD CONCEPT

The strategy of pre-loading the occupant facilitated inboard movement of the occupant, which minimized interaction with vehicle intrusion in the model simulation. Actual deployment testing of the TTC was then conducted on a rigid seat fixture to validate the model's prediction of pre-loading an inboard motion of the occupant.

Prototypes of the TTC were fabricated and tested with a seated dummy occupant. A 50th percentile Hybrid III male dummy was chosen for testing on a surrogate driver's side seat. Tri-axial pelvic acceleration was measured to determine the affect of the TTC loading on the pelvis was not injurious. A Grand Am seat was modified to accommodate TTC attachment locations on the front, bottom of the seat pan and inboard seatback structure. The upper portion of the TTC was placed behind the seatback cushion to investigate its ability to function with cushion interaction. The TTC was routed behind the lower back, over top the lap belt and fixed to the front mount point. High-speed video cameras were placed around the test setup to capture the dummy's kinematic responses during deployment. The overall setup of the static deployment evaluation in a surrogate seat is shown in figure 10.
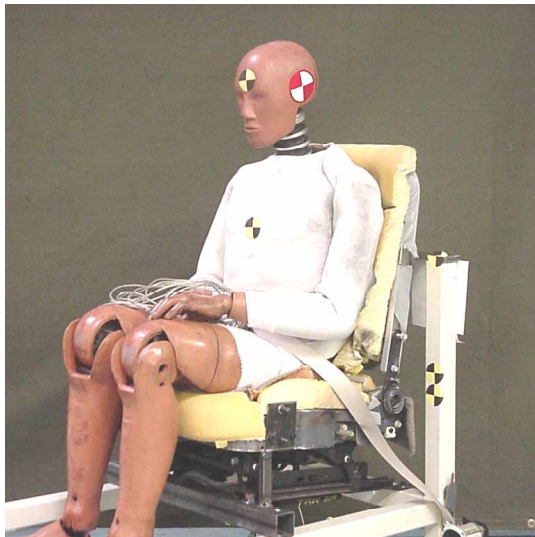
Figure 10. Hybrid III dummy in seat fixture

The TTC was deployed as designed. Time-to-position was evaluated from the video to be approximately 4 milliseconds when the TTC coverage was over the pelvis region. Review of the pressure response in figure 11 indicates very little pressure in the airbag during the first 4 milliseconds

due to the remote location of the pressure transducer within the airbag.
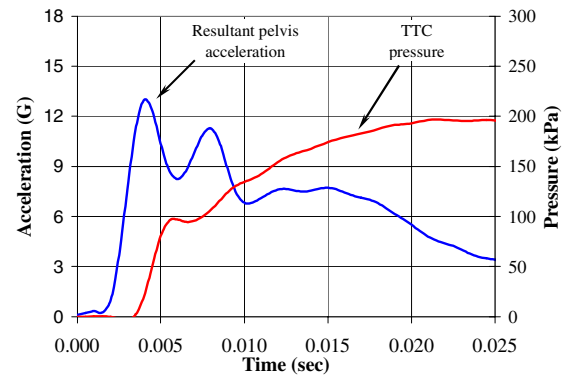
Figure 11. Timing of pressure response of TTC and pelvis acceleration for Hybrid III dummy

Maximum pelvis acceleration occurred very quickly due to rapid inflation of the relatively small inflatable volume of the airbag. The pelvis acceleration is due to the inboard movement of the TTC since there wasn't any door or intrusion for the airbag to react against and contact with the dummy. The peak acceleration occurred approximately 4milliseconds, which corresponds to the time-of-position of the TTC in the video analysis. Peak resultant acceleration was less than 13Gs indicating a minimal injury risk to the lower body during static deployment.

The static deployment test with the 50th male dummy demonstrated the TTC was capable of moving an occupant inboard as shown in figure 12. Reference lines are used in the figure to highlight the relative positions of the dummy before and after deployment of the TTC. Alignment of the target on the dummy's chest was used to observe inboard motion. Motion at the pelvis region was likely more substantial than movement observed at the chest target. Nevertheless, this test validated the computer model's prediction of inboard motion of an occupant without interacting with intrusion. The timing response with the TTC in the test further supported timing of occupant interaction in the computer model.
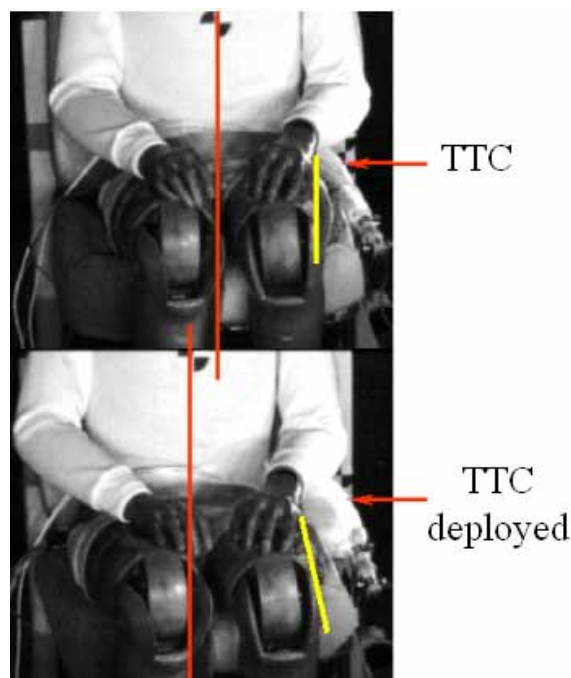
Figure 12. Video of inboard movement of Hybrid III dummy in seat fixture

TTC performance and airbag survivability would need to be evaluated in an actual dynamic environment under comparable impact conditions to an IIHS test.

DYNAMIC EVALUATION OF ITTC

Although the baseline modeling effort yielded a strongly correlated dynamic simulation upon which to design the TTC, concept validation required full dynamic testing.

Dynamic sled testing was designed to allow for repeatable testing at an impact severity equivalent to the full scale IIHS test. The goal was to generate similar rib responses to the baseline model and then evaluate the effectiveness of the TTC in reducing these rib deflections in a dynamic environment.

Sled Test Setup

A test apparatus was fabricated to allow the occupant to accelerate into a rigidly mounted Grand Am door at an appropriate acceleration pulse in order to evaluate the TTC in a dynamic environment. The occupant was restrained in a sliding seat mounted atop a sled that was allowed to move towards the door upon impact. This setup provided a repeatable test that could utilize the same door trim for multiple tests.

The door was reinforced with welded plates inside the door to support the inner door trim. The reinforced door structure would provide consistent material response and contoured geometry so that multiple tests could be maintained for each test. The height and fore-aft position of the door was positioned relative to the seated location of the SID-IIs dummy. Accuracy of the relative position between the armrest and SID-IIs abdominal ribs was equivalent to the IIHS test and the computer model setup. Figure 13 shows the SID-IIs in the dynamic sled test setup.
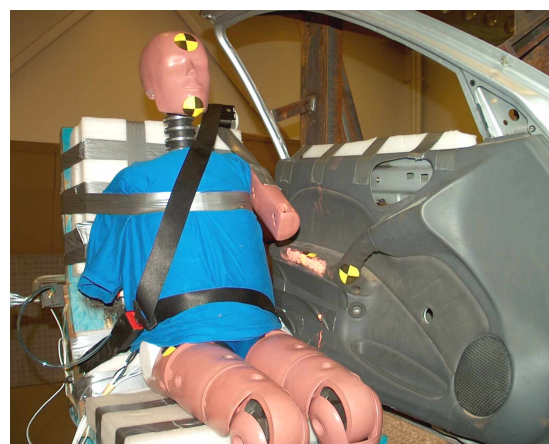
Figure 13. Sled test setup with SID-IIs dummy in seat fixture

A rigid seat was fastened to a sliding base to allow lateral movement of the occupant towards the door upon impact. This motion of the seat towards the door structure simulated intrusion of a vehicle crash.

A baseline test without the TTC was conducted to compare with results from tests conducted with the TTC.

Sled Test Results

Occupant kinematics of the dummy in the baseline sled test was similar to the dummy kinematics in the test with the TTC with the notable exception of limited motion of the pelvis towards the door fixture. The dummy moved laterally into the rigid door fixture and against the inner door panel as the sled decelerates for each of the two tests. The dummy in the baseline test interacts with the door structure in a relatively upright position exposing the ribs to considerable deflection as shown in figure 14.

**Figure 14. Video frames of baseline sled test without airbag**

However, a space created by the TTC between the dummy's thoracic/abdominal region and the door structure can be seen in the video frame shown in figure 15.

Figure 15. Video frames of baseline sled test with TTC airbag

The kinematic difference of the dummy in the TTC test reflected loading of the pelvis prior to contact of the thorax/abdomen with the door. This resulted in a favorable occupant kinematic, which reduced the rib deflection responses in the dynamic test. Also, the strategy of loading the pelvis with the TTC actually reduced the pelvis force as predicted in the computer model.

Thoracic rib deflections were significantly greater in the baseline test than the test with the TTC. The maximum thoracic rib deflections in both tests were the upper thoracic ribs. The maximum rib deflection in the baseline test was 37mm compared to 30mm for the test with the TTC. All of the rib deflection responses are shown in figure 16.
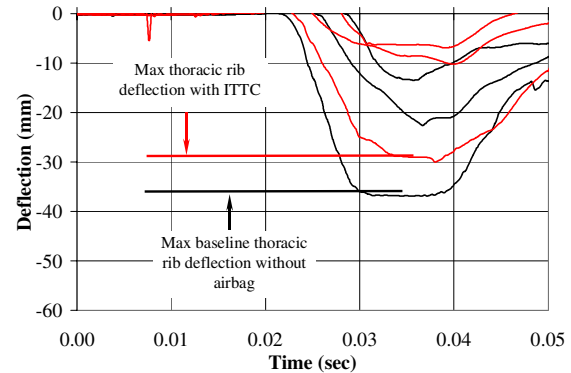
Figure 16. Comparison of thoracic rib responses in the sled test with and without the TTC

The responses of the rib deflections in the baseline test compared to the test with the TTC represented a reduction of 21%, 72%, and 31%, for the upper, middle, and lower thoracic rib deflections respectively. The reduced thoracic rib deflections with the TTC indicated a realistic improvement attributable to the airbag system.

However, the data from the baseline test indicated a much more severe impact on the occupant than expected, as shown in figure 17.
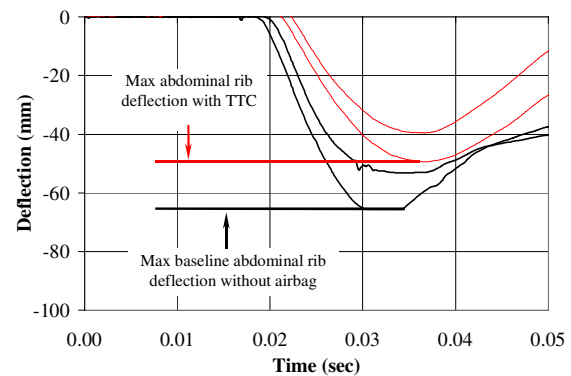
Figure 17. Comparison of abdominal rib responses in the sled test with and without the TTC

The upper abdominal rib deflection in the baseline test was 53mm while the lower abdominal rib potentiometer was deflected to its maximum amount of 65mm. The maximum abdominal rib deflection in the test with the TTC was the upper abdominal rib, unlike the maximum deflection occurring at the lower abdominal rib in the baseline test. This represented a 40% improvement between the maximum rib deflections for the upper abdominal rib in the test with the TTC compared to the

maximum deflection for the lower abdominal rib of the baseline test.

Although the baseline occupant responses indicated an impact severity greater than expected, results supported the potential improvement in using the TTC to reduce occupant loading in a dynamic impact scenario. The TTC functioned as designed by preloading the pelvis prior to door impact, applying an inboard lateral force to the occupant inboard, and thus reducing the severity on the thorax and especially the abdominal region. Although pelvic loading was not a primary injury concern throughout this project, the sled testing demonstrated the capability of the TTC to significantly reduce peak lateral pelvis forces. Table 2 is a comparison of the peak occupant responses and percent difference for the tests with the TTC and baseline dynamic sled test.

Table 2.
Response comparison of maximum occupant responses for baseline and TTC sled tests

Occupant Response	Baseline	TTC	% Diff
Upper thoracic rib deflection (mm)	37	29	-21%
Middle thoracic rib deflection (mm)	22	6	-72%
Lower thoracic rib deflection (mm)	13	9	-31%
Upper abdominal rib deflection (mm)	53	49	-8%
Lower abdominal rib deflection (mm)	65	39	-40%
Pelvic force (N)	2900	1200	-59%

DISCUSSION

Computer analysis confirmed that an approach of interposing an inflatable cushion between vehicle occupants at the ribs and a vehicle's intruding side structure may be problematic when attempting to limit rib deflection, particularly for small-stature occupants. However, computer modeling of the TTC airbag have shown to affirmatively load the occupant's pelvis inboard from intrusion during IIHS crash test simulations and subsequently mitigated the effects of contact and interaction between the occupant's rib and the intruding vehicle structure.

A significant reduction in thoracic and abdominal rib deflection as a result of the inboard

pelvis interaction with the TTC airbag was later demonstrated in very severe dynamic sled tests intended to simulate the IIHS side-impact condition. Review of the kinematic response of the SID-IIs dummy in the sled test showed noticeable space created by the TTC between the dummy's thoracic/abdominal region and the door structure, which minimized the interaction with the simulated intrusion.

The effect of the deployment timing was illustrated in computer models by comparing the pelvic force time history for the lateral preload system of the TTC and more typical functions of side-mounted airbags, which represents more mainstream designs of current side airbag systems. The inboard lateral preload to the occupant by the TTC would seem to work as well only if the deployment timing of the TTC were sufficiently rapid in order to offer the demonstrated potential increased performance benefit.

Peak pelvis acceleration responses measured in actual static deployment testing occurred very quickly due to rapid inflation of the relatively small inflatable volume of the TTC airbag. The inboard pelvis acceleration of a dummy was created without a door surface to react against as would be required by typical side airbags. The peak acceleration created by the TTC airbag occurred approximately 4milliseconds, which corresponds to the time-of-position of the TTC in the video analysis. This rapid inflation would be advantageous in real-world side-impacts by quickly positioning the TTC prior to door intrusion.

The current TTC development involved evaluation of design iterations in a simulated dynamic environment. MADYMO was used extensively as the initial tool for optimizing TTC performance and will likely continue, to a lesser degree, to be used to guide design decisions for concept feasibility

CONCLUSIONS

Feasibility of significantly reducing rib deflection in the IIHS test by preloading the pelvis only, independent of vehicle intrusion, has been demonstrated with a TTC airbag device. Tests with the TTC design at various component and system levels have validated the computer model predictions. Potential benefits due to timing advantage of the TTC in this severe crash environment appear attainable as shown in figure 18.
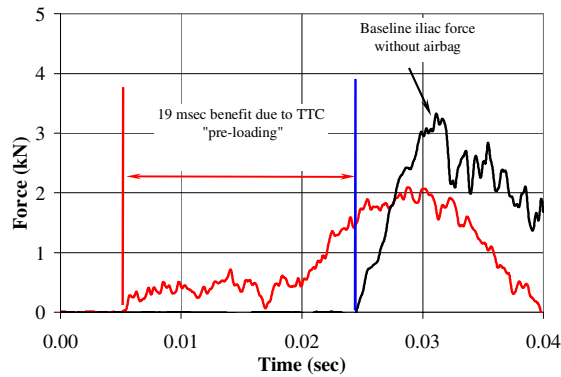
Figure 18. Potential benefit due to TTC timing

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